Operative Techniques in
Thoracic and
Cardiovascular Surgery

Bilateral Sequential Lung Transplantation

Mani Ali Daneshmand, MD, Shu S. Lin, MD, John C. Haney, MD, Matthew G. Hartwig, MD, and Robert D Davis, MD

Introduction

First performed in 1984, lung transplantation techniques and survival have improved considerably in the last 3 decades. Advances in immunosuppression, surgical technique, postoperative care, and patient selection have resulted in more than a 500% reduction in mortality. Along with that, improvements in donor management and selection have resulted in an explosive expansion of the therapy to almost 4000 single and double lung transplants worldwide. Unfortunately, despite the expansion of this therapy, more than 100,000 patients still die each year of advanced lung disease (Figs. 1-12).

Department of Surgery, Duke University Medical Center, Durham, NC
Address reprint requests to Mani Ali Daneshmand, MD, Duke University Medical Center, 2301 Erwin Rd, DUMC 3867, Durham, NC 27710.
E-mail: mani.daneshmand@dm.duke.edu; danes002@gmail.com

1522-2942/$-see front matter
http://dx.doi.org/10.1053/j.optechstcvs.2014.09.001

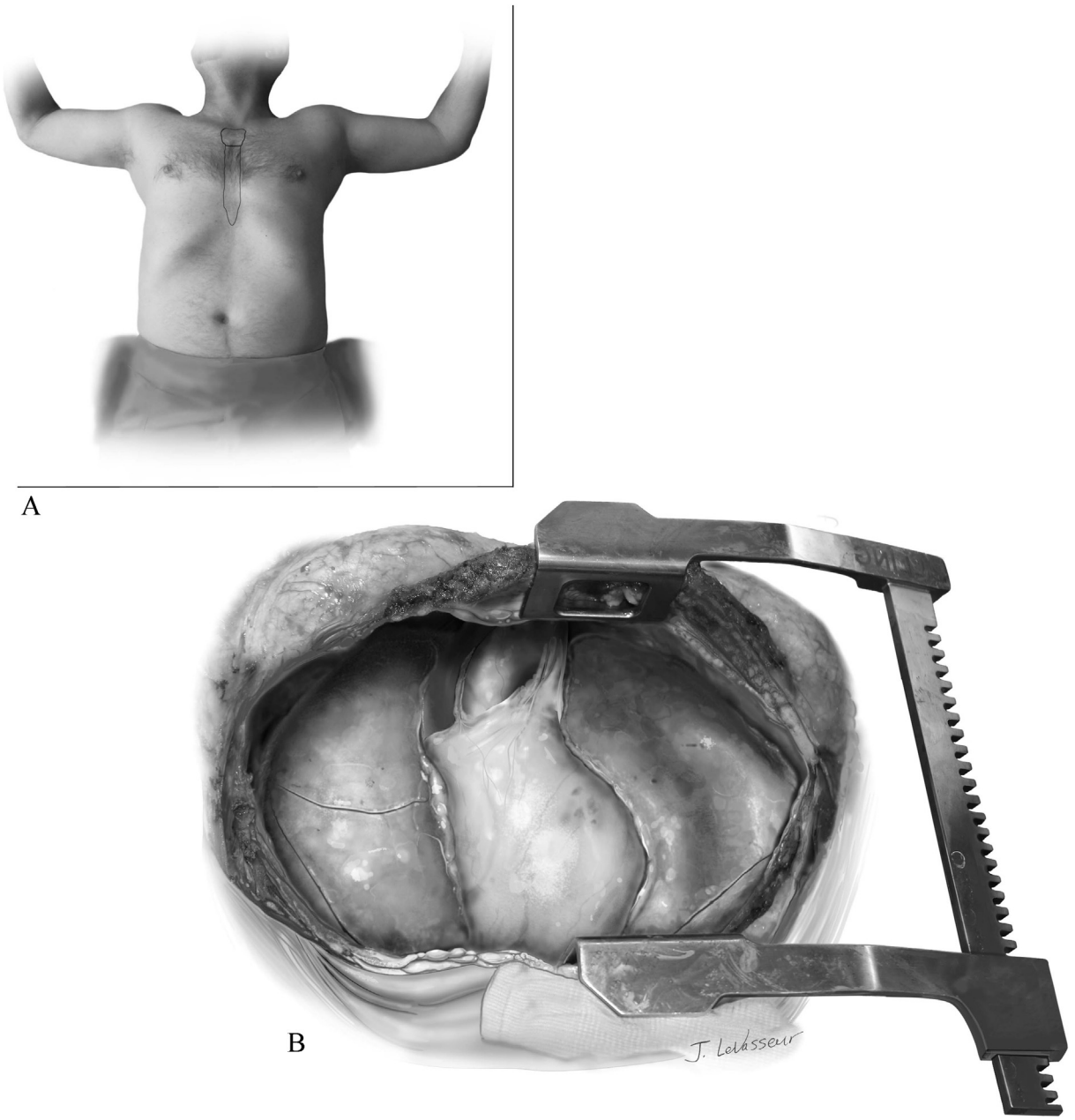

Figure 1 After induction of general anesthesia, the patient is dual-lumen intubated and monitoring lines, including a Swan-Ganz catheter and a large-bore IV access, are placed in the left neck. Two arterial lines are placed, 1 in the upper extremity and 1 in the femoral artery. The patient is positioned supine with arms elevated to almost 90° (A). This allows access to both axilla and facilitates the bilateral transsternal thoracotomy (clamshell incision). The incision starts in the right axilla and courses along the fourth interspace below the nipple in men (along the inframammary crease in women) and across the sternum to a mirror-image incision on the opposite side. The pectoralis major is divided. The latissimus dorsi is usually spared. At the level of the chest wall, the interspace that extends to the axilla is identified. This is usually the fourth interspace. The intercostal muscles are divided and both internal mammary arteries and veins are ligated and divided. The sternum is divided to connect the right and left chest. (B) The retrosternal connective tissue is dissected off the bone to the level of the innominate vein superiorly and to the diaphragmatic reflection inferiorly. A retractor is placed in the midline at the sternal edges and the clamshell incision is opened slowly. Division of the intercostal muscles is extended posteriorly within the thoracotomy to facilitate exposure and to prevent tearing of tissue. IV = intravenous.

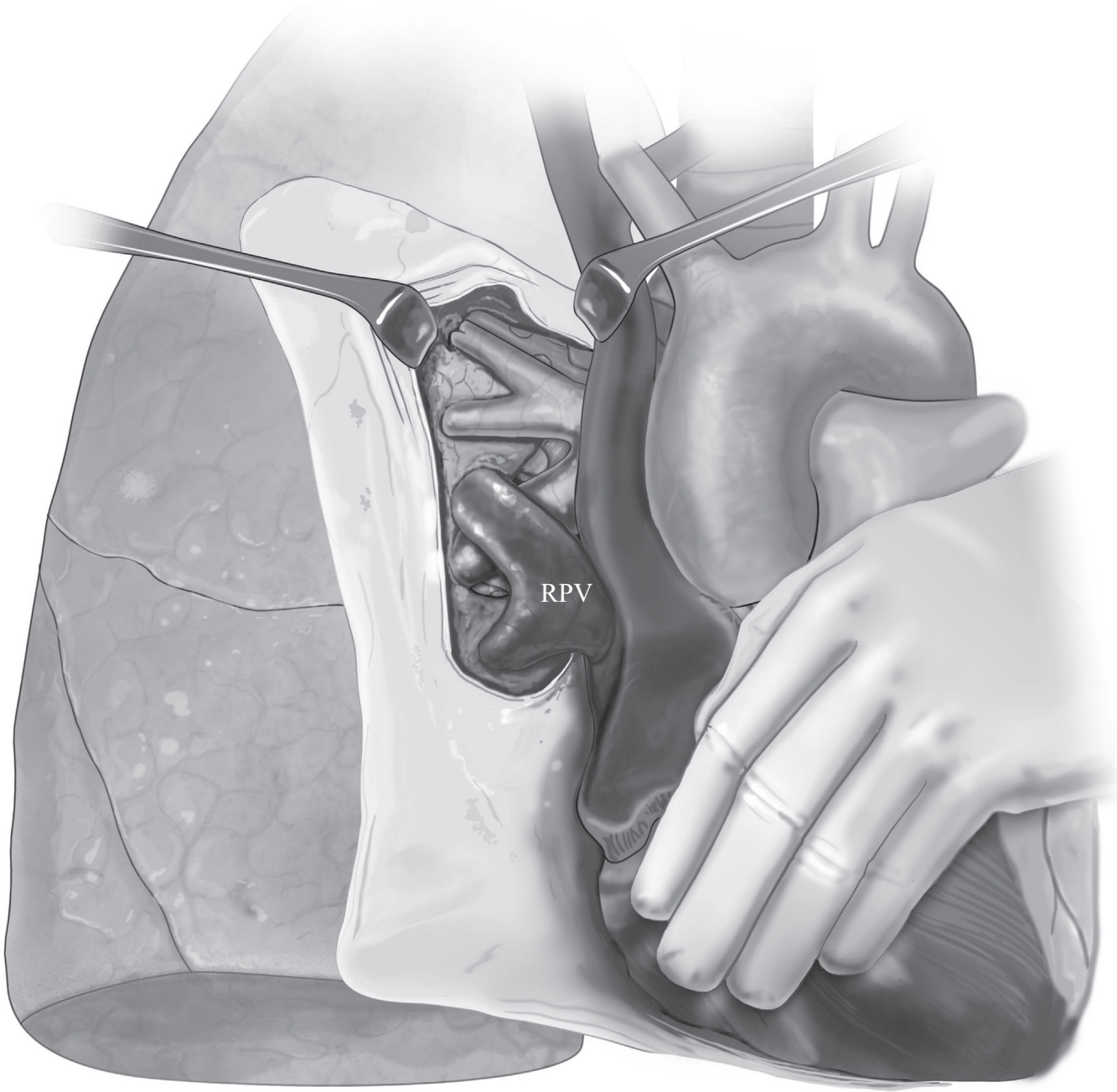

Figure 2 The anterior pericardium is opened in the midline and the heart is exposed. The superior vena cava (SVC) is circumferentially dissected and reflected medially to expose the right pulmonary artery (RPA). Within the mediastinum, the RPA is circumferentially dissected. The right pleural space is entered through the pericardium at the level of the RPA and this is extended caudally to dissect the right superior and inferior pulmonary veins from the pericardium. Care is taken to ensure that the phrenic nerve is not injured. The dissection is then carried across the pericardium into the pleural side of the hilum. This intrapericardial dissection speeds the mobilization of the hilar structures and allows for most of the dissection to be performed while maintaining bilateral ventilation, thereby preventing prolonged respiratory acidosis, hypoxemia, or hemodynamic instability.

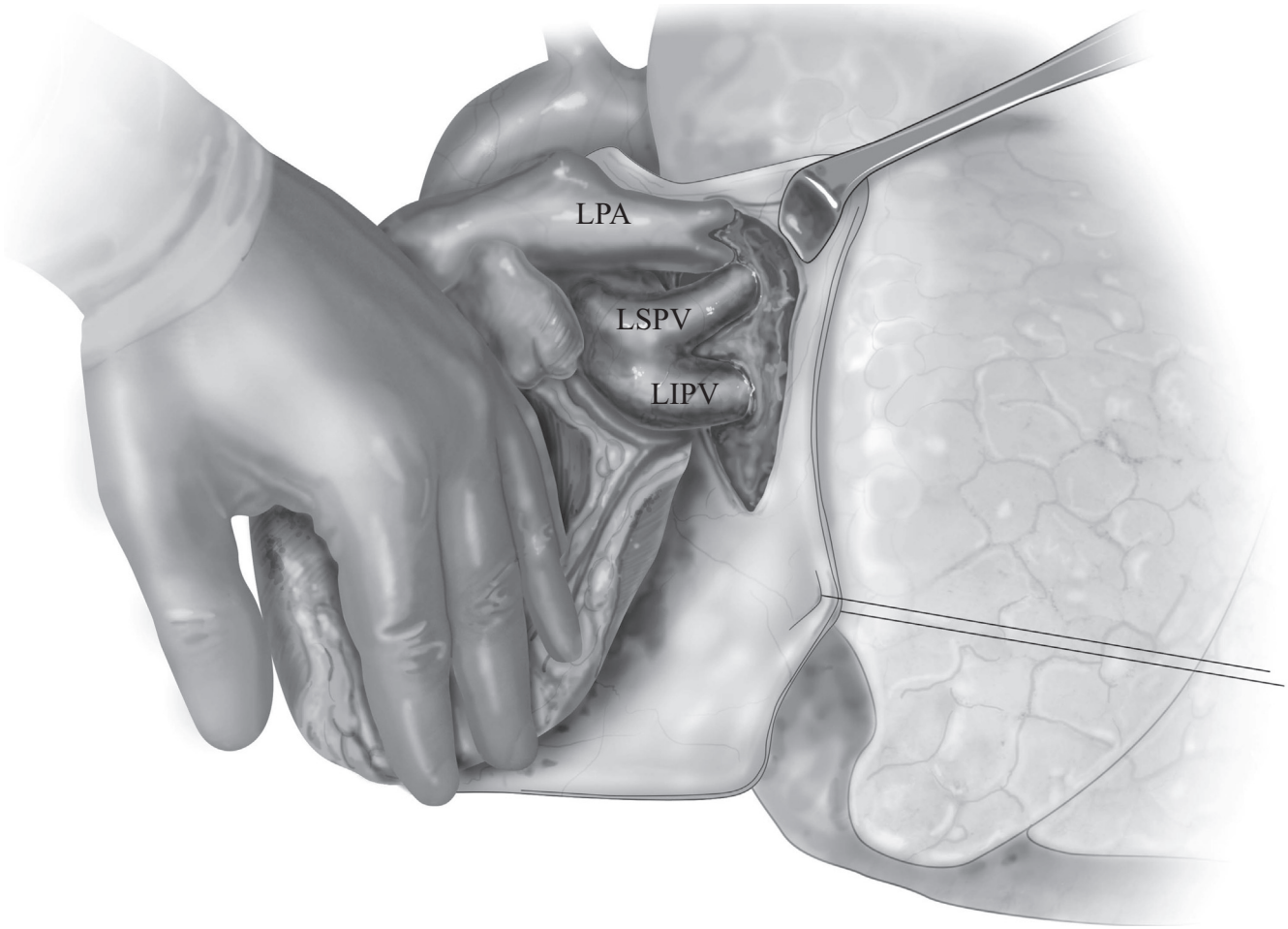

Figure 3 The apex of the heart is then elevated out of the pericardial well to expose the intrapericardial left pulmonary artery (LPA) and left-sided veins. In a similar fashion, the left-sided hilar vasculature is dissected first from the pericardium and then intrapleurally. Again, meticulous care is taken to avoid any injury to the phrenic nerve by traction, direct trauma, or electrocautery.

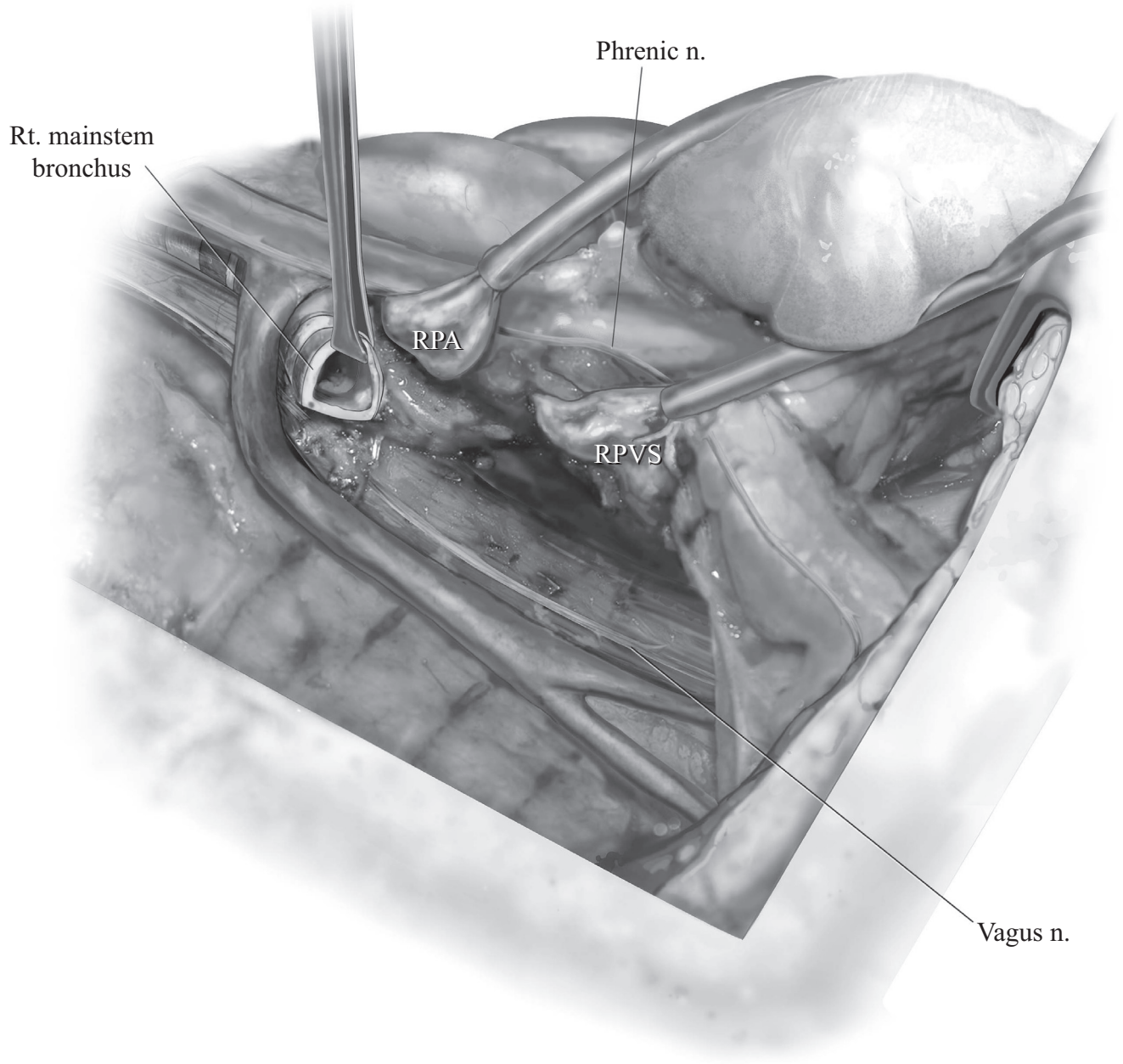

Figure 4 After complete dissection of the hilar vasculature, the right lung is deflated. The truncus anterior and on-going pulmonary arteries are divided with a vascular load gastrointestinal anastomosis (GIA) stapler. The right superior and inferior pulmonary veins are similarly divided out in the hilum of the lung with a vascular staple load. The artery and vein branch tips are snared and then retracted medially, exposing the airway. The upper lobe bronchus and bronchus intermedius are divided and the peribronchial lymphatic tissue is dissected in a limited fashion to control hemorrhage. Frequently, the vagus nerve is engulfed by the peribronchial lymphatics. Without cautious dissection, the vagus may be injured. The right main stem bronchus is then trimmed sharply to the level of lymphatic dissection in preparation for anastomosis. n = nerve.

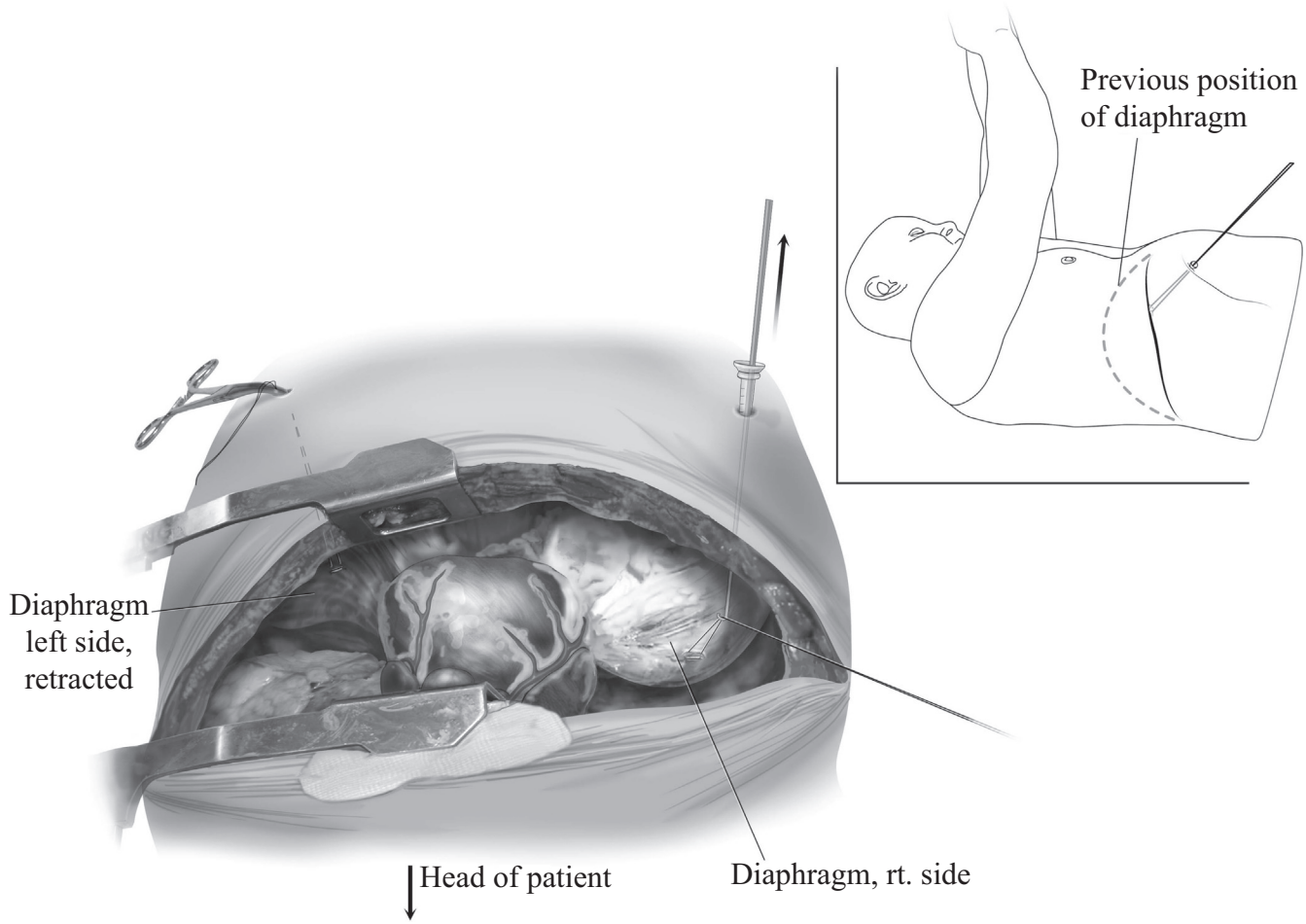

Figure 5 In patients with smaller chest cavities, such as those with interstitial lung disease, a diaphragmatic retraction stitch can be used to enlarge the thoracic cavity to facilitate lung transplantation. A 36-in 0 silk or braided nylon suture is placed as a figure of 8 in the middle of the central tendon of the diaphragm. This suture is then brought out inferolaterally through a 14-gauge angiocatheter and the diaphragm is retracted inferiorly. This is secured under tension at the skin level with a hemostat on the suture. This retraction suture is usually kept in place until the patient is ready for weaning from the ventilator.

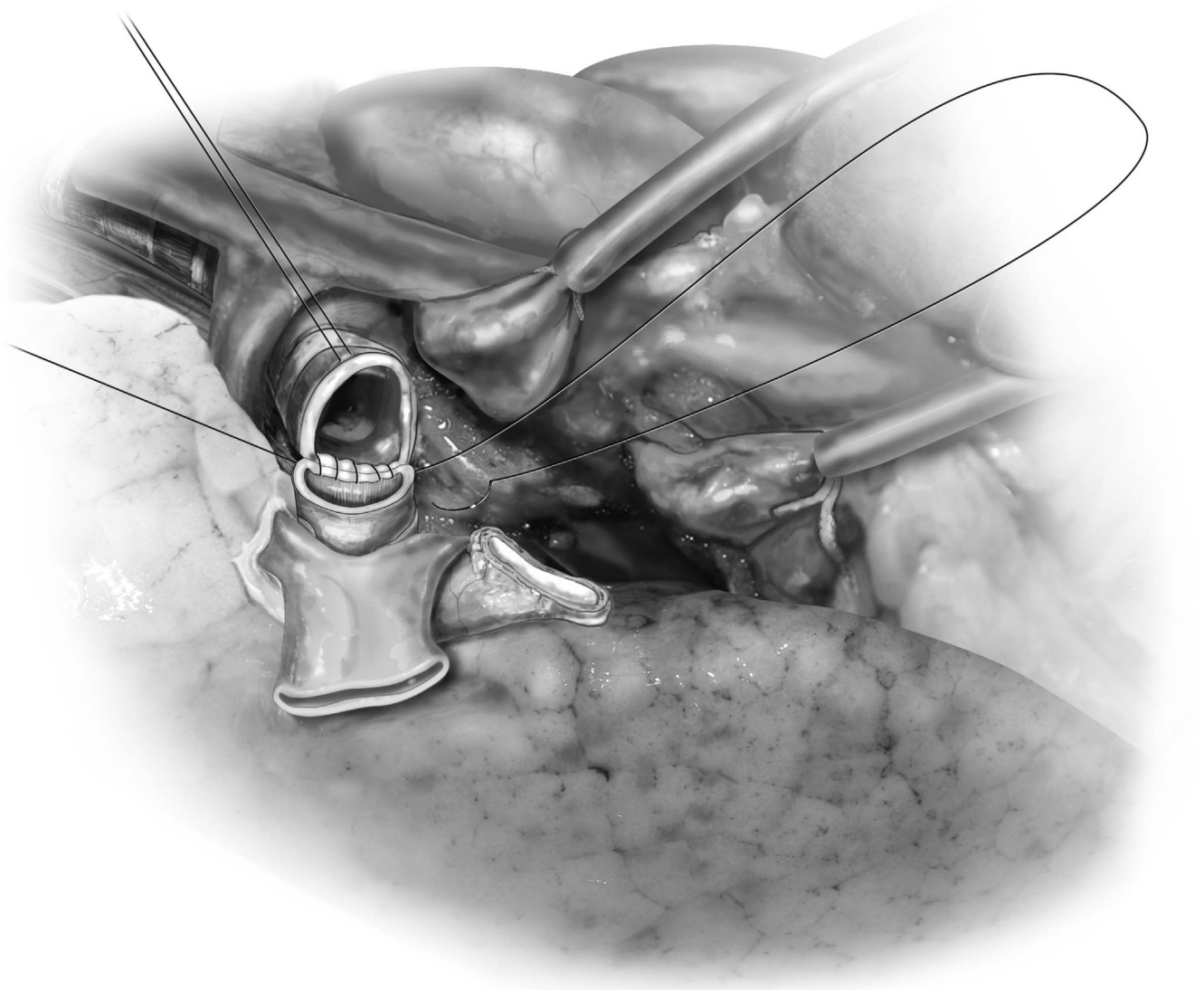

Figure 6 The bronchial anastomosis is preformed in a running fashion using a high tensile strength 4-0 monofilament absorbable suture such as PDS (Ethicon). This must be a tension-free anastomosis with no gaps. After completion of the membranous bronchial anastomosis, the same suture is used to complete the cartilaginous portion of the bronchus.

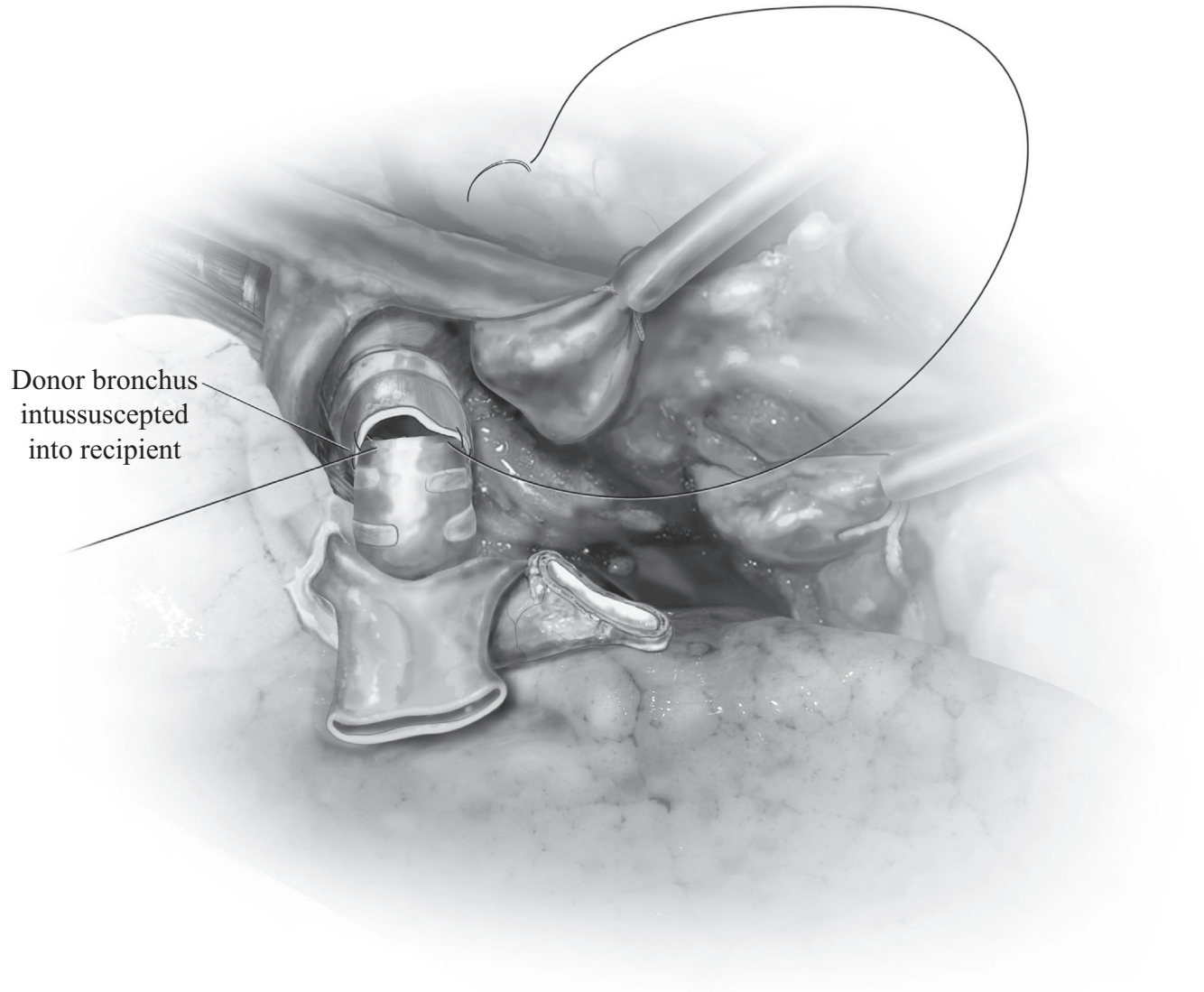

Figure 7 The cartilaginous bronchus usually requires intussusception to decrease likelihood of air leak. Typically, the donor's bronchus is smaller than the recipient's is and therefore it is placed within the recipient bronchus. To facilitate this intussusception, the first bite of suture on the cartilaginous portion of the donor bronchus is brought from inside to out. This is then transitioned to a bite on the recipient bronchus also from inside to out, thus mating the outside of the donor bronchus to the inside of the recipient bronchus. The anastomosis is then carried in a running fashion to completion. The anastomosis is submerged in saline, and a ventilation test is performed to identify leaks. Typically, there is no need to buttress the anastomosis with any mediastinal tissue.

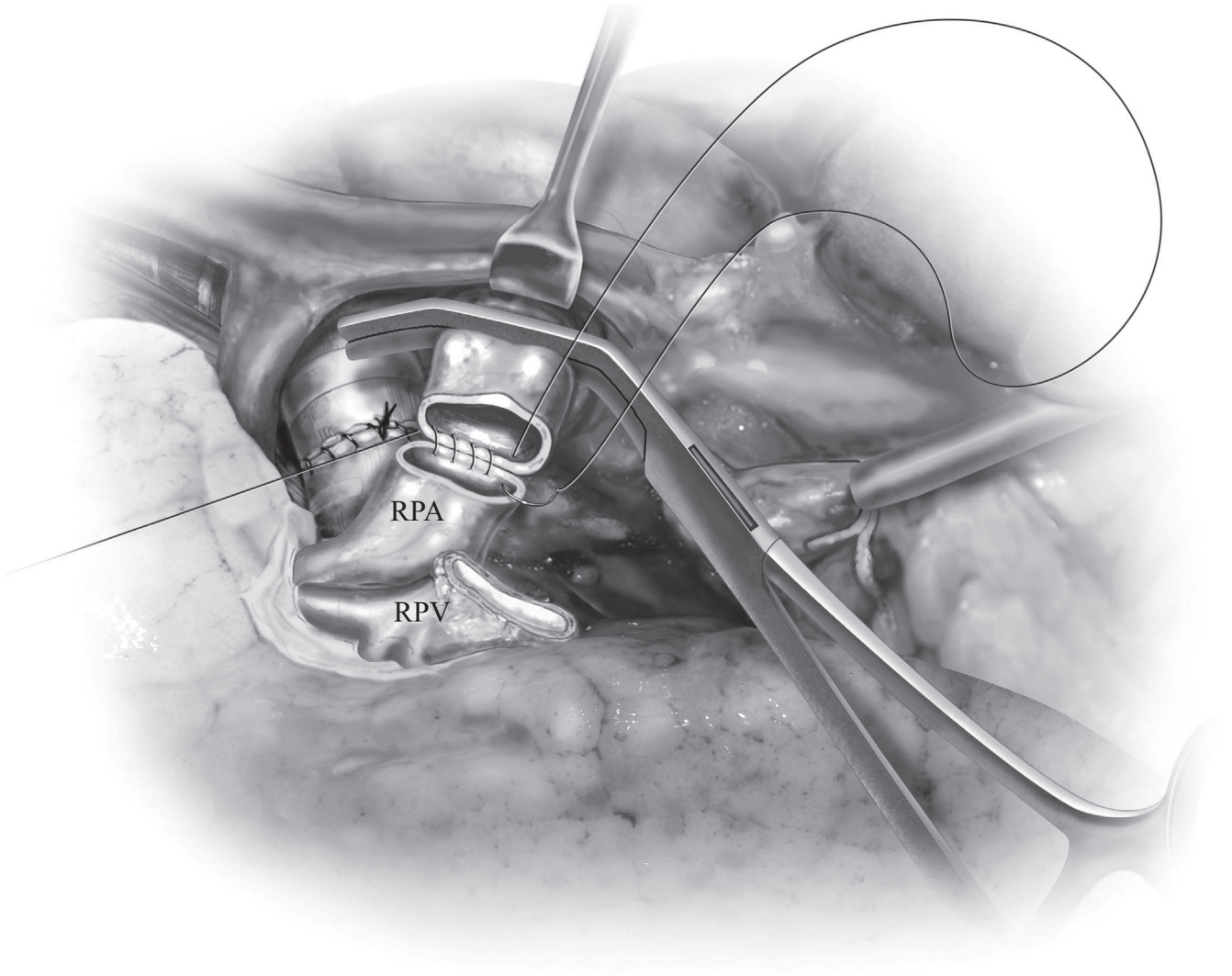

Figure 8 Upon completion of the bronchial anastomosis, the patient is systemically heparinized to an ACT of 200-300 seconds. A Satinsky clamp is placed on the pulmonary artery (PA) as proximal as possible. The staple line is excised sharply and the artery is flushed with heparinized saline. An iced laparotomy pad is placed behind the donor lung to elevate it and simulate its "inflated" position. The donor and recipient PAs are trimmed to size and sewn together in a running fashion using a 6-0 monofilament polypropylene suture. The recipient PA can be particularly fragile after years of chronic pulmonary disease. Minimal torque or tension should be applied to this vessel during and after anastomosis. ACT = activated clotting time.

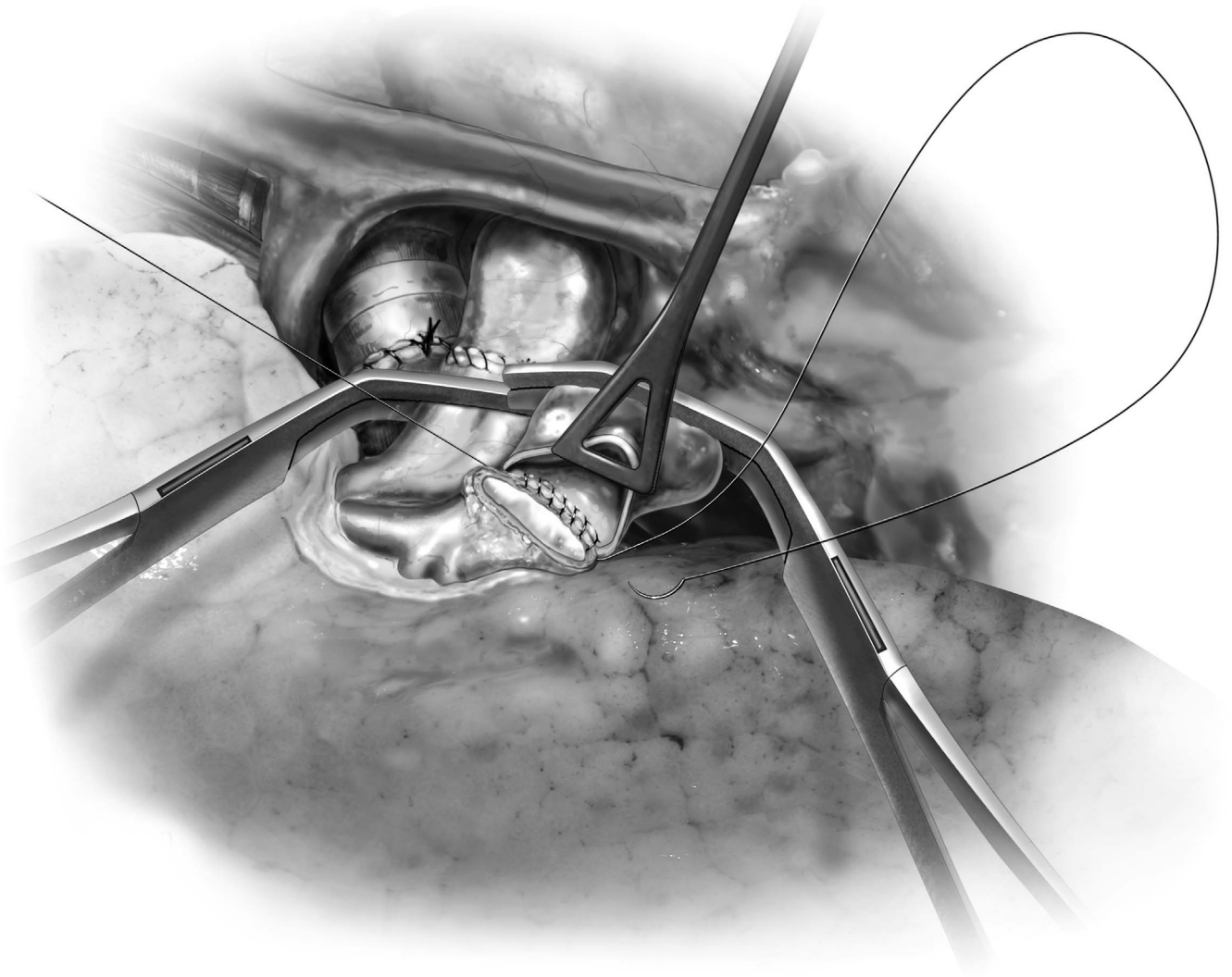

Figure 9 Once the PA anastomosis is complete, the vascular clamp is moved distal to the anastomosis to test its integrity and any additional corrective stitches are placed to provide hemostasis. A large Satinsky clamp is placed on the left atrium, and the staple lines of the pulmonary veins are trimmed. The bridge of tissue between the veins is incised, and the 2 veins are connected to make 1 large left atrial orifice. A Pennington clamp is placed on the anterior portion of the recipient left atrium and is retracted toward the assisting surgeon for exposure. The donor left atrium is trimmed to size and sewn to the recipient using 5-0 monofilament polypropylene suture. It is important to ensure intimal-to-intimal apposition along the entirety of this anastomosis. This ensures hemostasis and decreases the risk of thrombus formation within the left atrium. Once the posterior wall of the anastomosis is complete, the Pennington clamp can be removed and the anterior portion of the anastomosis is completed. PA = pulmonary artery.

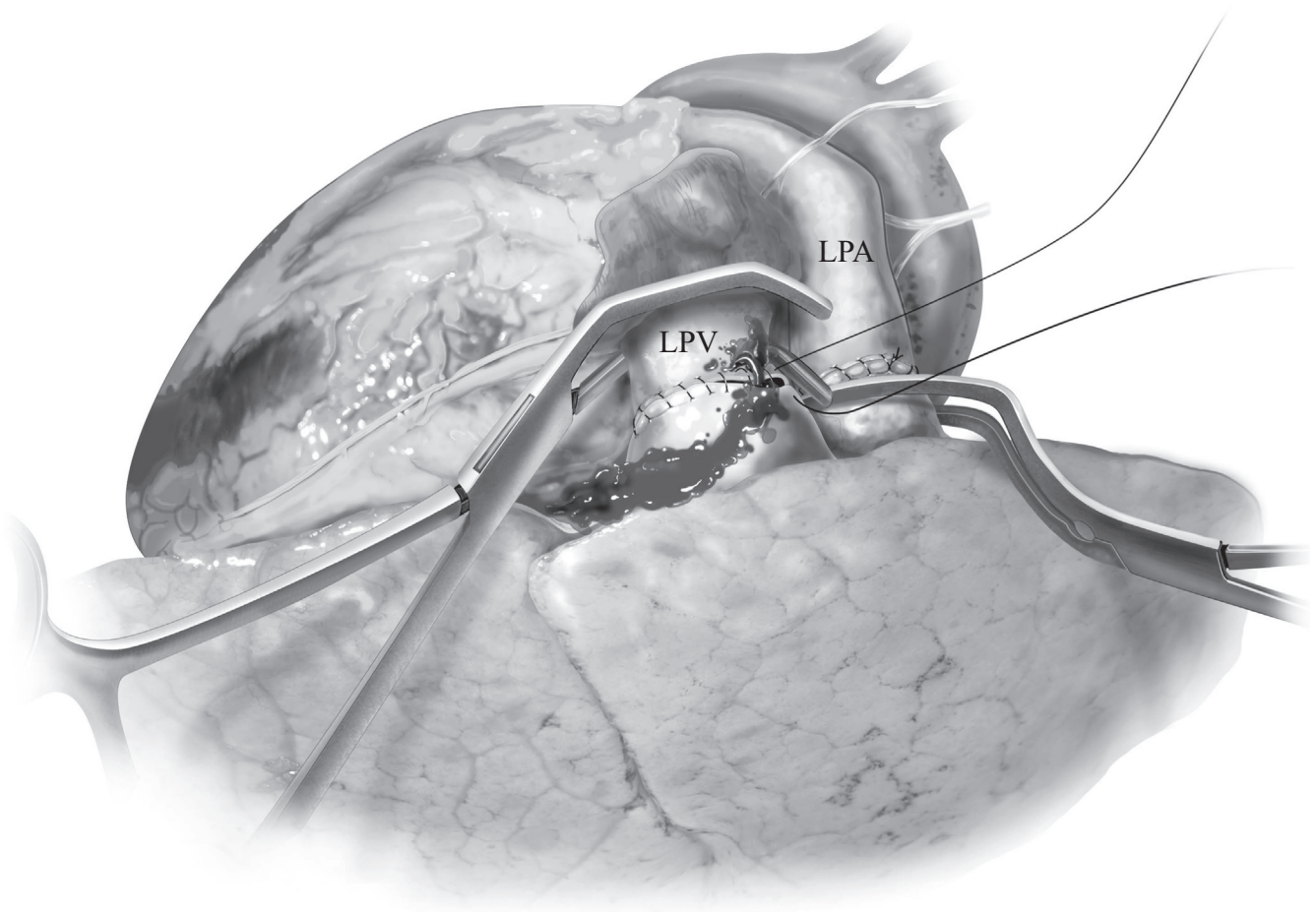

Figure 10 Before completion of the left atrial anastomosis, the clamp on the pulmonary artery is partially released to flush remaining preservation solution and air out of the donor lung. The lung is gently ventilated to ensure that all air is forced out of the pulmonary veins. The clamp on the left atrium is then partially released to completely de-air the heart. The suture is then securely tied, completing the anastomosis. The left atrium is completely unclamped, but the pulmonary artery remains partially occluded. Over the course of the next 10-20 minutes (depending on the pulmonary artery pressure), the lung is gently reperfused in a controlled fashion and the pulmonary blood flow is gradually increased. After 5 minutes of this controlled reperfusion, the lung is ventilated with low FiO_2 (usually RA), low pressure, and inhaled nitric oxide. RA = Room Air

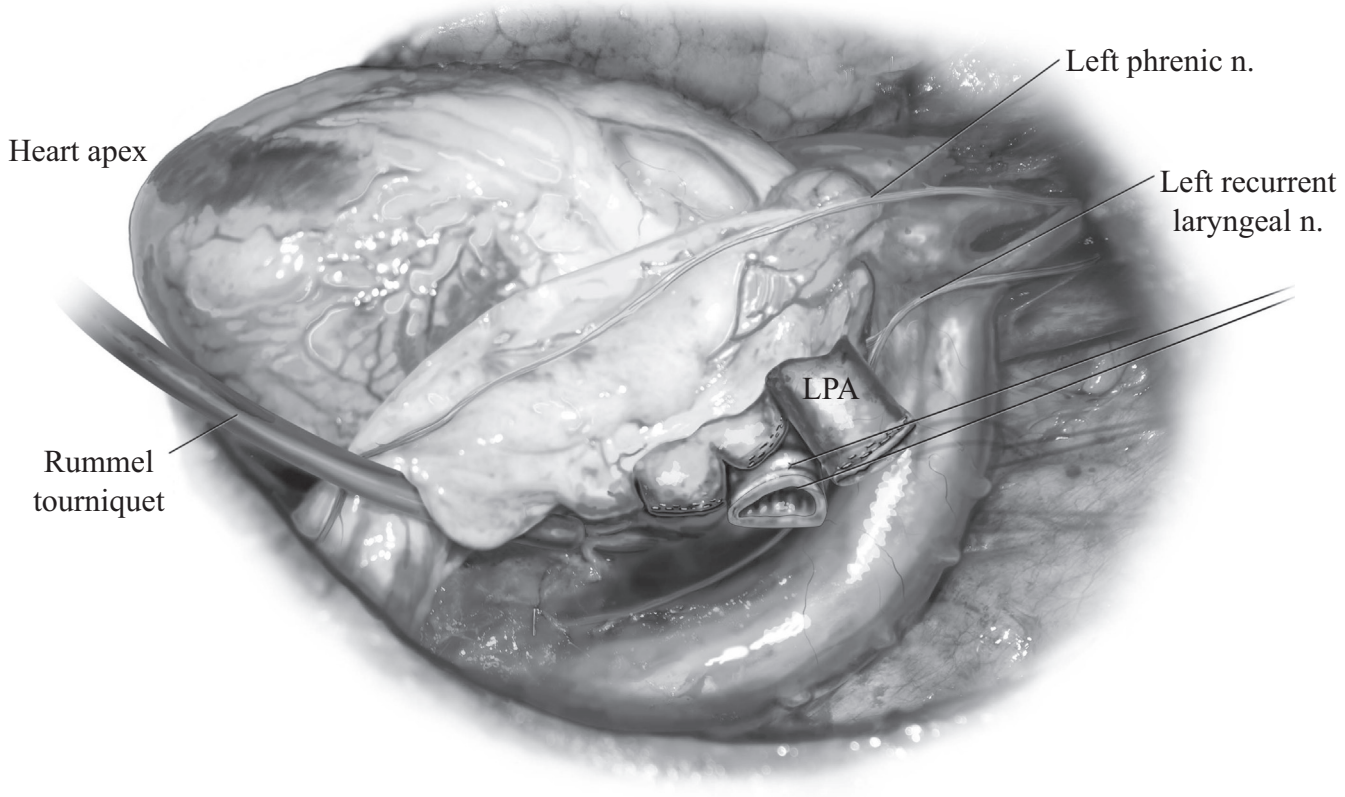

Figure 11 After the first lung has been reperfused, the contralateral lung (in this case the left lung) is disconnected from the ventilator, and the pulmonary artery, veins, and bronchus are divided similar to the first side. To facilitate exposure on the left side, the apex of the heart is eviscerated from the pericardium and a 2-0 silk suture is placed on the posterior pericardium half way between the left inferior pulmonary vein and the diaphragm. This is covered with a Rummel tourniquet and used to support the apex of the heart in the eviscerated position. An additional 2-0 silk suture and tourniquet can be used on the pleural side of the pericardial edge at the level of the pulmonary veins. This provides excellent exposure of the left hilum for anastomoses. Frequently, the use of small boluses of inotropic agents is necessary to treat transient hypotension. Effective communication between the surgeon and the anesthesiologist before manipulating the heart allows for optimization of drug delivery and patient hemodynamics.

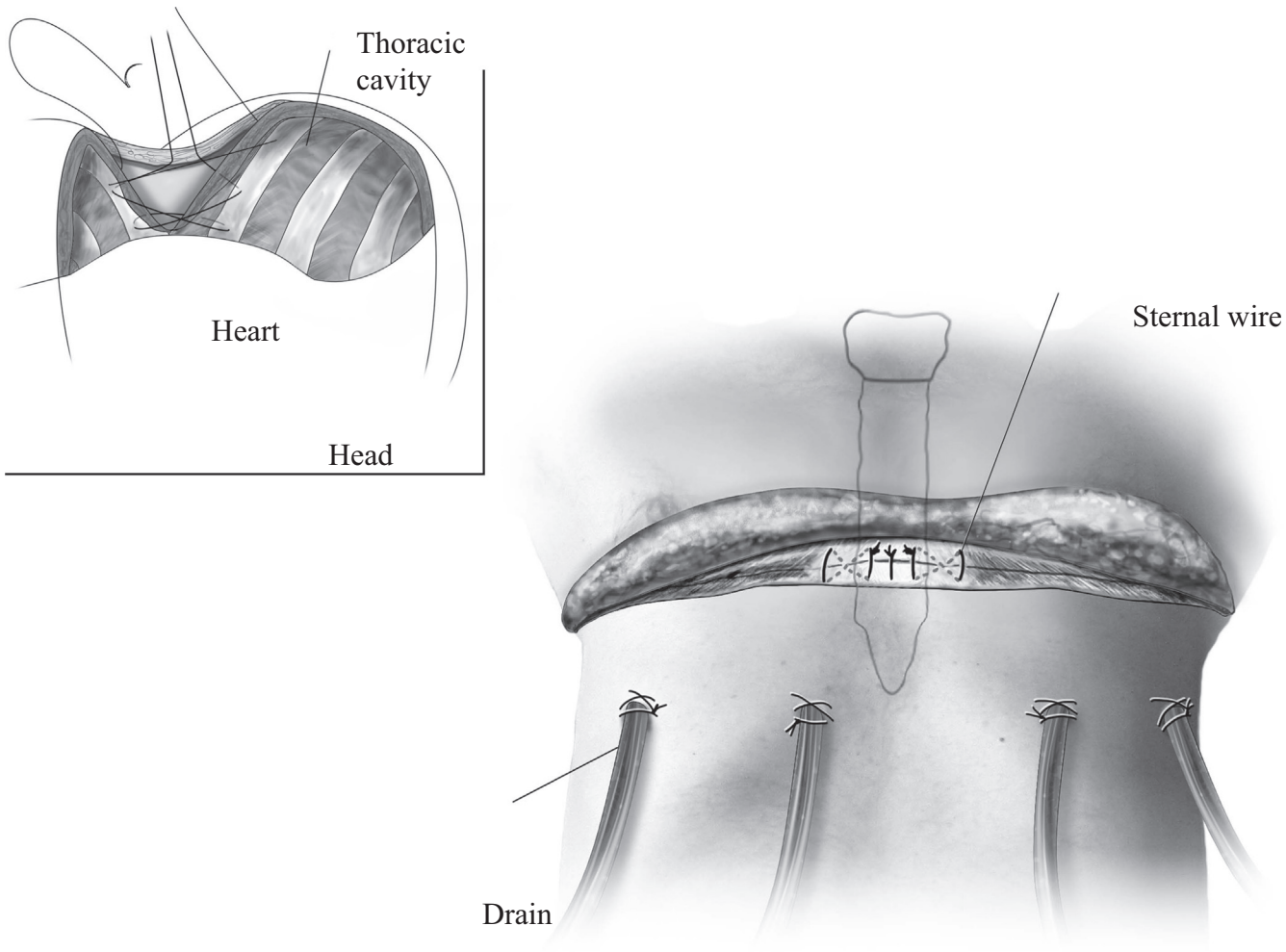

Figure 12 After explantation of the old lung and before implantation of the donor lung, each thoracic cavity is prepared for its ultimate closure. Initially, 2 no. 1 high tensile strength monofilament absorbable sutures (Maxon) are placed in a figure-of-8 pattern around the opened interspace (inset). These are secured with a hemostat and not tied until the chest is closed. Placing these sutures before implantation of the donor lung is significantly easier. Additionally, before implantation, all posterior chest tubes are placed. Once the transplant is complete, anterior and mediastinal chest tubes are placed. The pericardium is loosely approximated and the sternum is approximated with 3 no. 5 or no. 7 stainless steel wires (depending on the quality of the sternum). Several more no. 1 Maxon sutures are used to completely close the interspace.

Conclusion

After completion of the bilateral sequential lung transplantation, the dual lumen endotracheal tube is replaced with a single lumen tube, and fiberoptic bronchoscopy is performed to ensure bronchial anastomosis patency and to clear any secretions. In the intensive care unit, the patient is resuscitated. Crystalloid is avoided to prevent significant pulmonary edema. As soon as the patient is hemodynamically stable and any coagulopathy is corrected, a thoracic epidural is placed for pain control and the patient is weaned from the ventilator and extubated. All lung transplant patients undergo extensive evaluation postoperatively to ensure they have no aspiration before feeding. Any patient who is aspirating would undergo feeding tube placement and should not be permitted ANY oral intake until his or her aspiration resolves.

All patients undergo daily bronchoscopic examination to assist in clearance of secretions and to identify any airway problems early. As part of the postoperative convalescence, all patients are encouraged to return to rigorous physical activity and, in fact, are not discharged home until they are walking more than 1 mile daily.

After discharge, all patients are required to attend cardiopulmonary rehabilitation for no less than 23 sessions at a rate of 5 sessions a week. All patients are evaluated early in the postoperative period for gastroesophageal reflux, and those with reflux undergo Nissen fundoplication after they have recovered from their lung transplant procedure.